

Framework of Indoor User Localization Using Wi-Fi Fingerprinting and Visual Clues

Thesis submitted in partial fulfillment of the requirements for the award of degree of

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In

Computer Science and Engineering

Submitted By

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CERTIFICATE

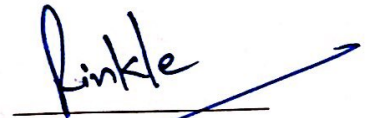
I hereby certify that the work which is being presented in the thesis entitled, "*Framework of Indoor User Localization Using Wi-Fi Fingerprinting and Visual Clues*", in partial fulfillment of the requirements for the award of degree of Master of Engineering in *Computer Science and Engineering* submitted in Computer Science and Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of Dr. Rinkle Rani and refers other researcher's work which are duly listed in the reference section.

The matter presented in the thesis has not been submitted for award of any other degree of this or any other University.



(Ronika Thind)

This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge.



(Dr. Rinkle Rani)

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Computer Science and Engineering Department

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Abstract

Smartphone industry is a steadily growing one, with its development comes various positioning sensors to fulfill the increasing demand for location based services. Most of these services need additional hardware which causes extra cost and lacks in availability to the common masses. Though GPS receiver comes to the rescue of such services with a high accuracy gradient but, has major drawback of signal attenuation in an indoor environment. In this research we are taking advantage of the built in sensors and their mostly available on tap connectivity with the wireless network .The main advantage of the proposed technique is the low cost involved with no extra hardware requirement. But, the cons of the proposed method like multipath fading due to signal attenuation are not avertible and had been worked upon through the course of this research by adding visual database of a user's position .

In the presented thesis we are working with user localization method in an indoor environment using Wi-Fi fingerprinting method and affirming the results obtained with visual clues. Field experiments have been carried out using indoor positioning system in smartphones. The data obtained have been worked upon using machine learning algorithms to increase the accuracy of the results. The positioning of a user has been tested by using the image database of the same user. The accuracy of the results obtained is empirically around 2.4 meters. The advantage of the proposed framework is that by working on the two off the shelf commercial systems and combining their assets we have built a system that provides us with better result.

Table of Contents

Chapter 1	ix
Introduction.....	1
1.1 Background.....	1
1.2 Location based services and applications	4
1.3 Indoor Localization Problem	7
Chapter 2.....	12
Literature Survey	12
2.1 Need of User Localization	12
2.2 Various Indoor Positioning Systems.....	14
2.3 Previous Work	15
Pallas: Self-bootstrapping fine-grained passive indoor localization using WiFi monitors	15
Chapter 3.....	18
Research Problem	18
3.1 Problem Statement.....	18
3.2 Research Gaps.....	19
3.3 Research Objectives.....	19
Chapter-4.....	21
Overview of Existing Localisation Technique	21
4.1 Positioning Techniques.....	21
4.1.1 GPS	22
4.1.2 A-GPS System	23
4.1.3 Wi-Fi based system.....	23
4.1.4 INS (Inertial Navigation System)	24
4.1.5 Other Systems	24

4.1.6 Comparison of Positioning Methods	25
4.2 Positioning with Smartphones	26
4.2.1 Smartphone Evolution	26
4.2.2 Leading Functionalities of Smart phones	27
4.2.3 Operating Systems in Smart phones	29
4.2.4 Sensors in Smartphones	30
4.3 Estimation Methods of Indoor Localization	31
4.3.1 Cell of Origin (COO).....	32
4.3.2 Trilateration.....	33
4.3.3 Fingerprinting	33
4.3.4 Comparison of Positioning Techniques.....	35
4.4 Measurement Criteria of Positioning	36
4.4.1 Time of Arrival (TOA)	36
4.4.2 Time Difference of Arrival (TDOA)	37
4.4.3 Angle of Arrival (AOA).....	38
4.4.4 Received Signal Strength (RSS)	39
4.4.5 Comparison of Four Measurement Models	39
4.6 Fingerprinting Algorithms	40
4.6.1 Nearest Neighbor Algorithm (NN).....	40
4.6.2 k-Nearest Neighbor Algorithm (k-NN)	41
4.6.3 Weighted k- Nearest Neighbor Algorithm.....	41
Chapter 5.....	42
Framework	42
5.1 Phase 1	42
5.2 Phase 2	44

5.3 Phase 3	44
Chapter 6.....	46
Results and Analysis	46
Chapter 7.....	48
Conclusion and Future Scope	48
7.1 Conclusion	48
7.2 Future Work	49

List of Figures

1.1 Global smartphone sales value from 2012 to 2017.....	2
1.2 Global Wi-Fi enabled equipment shipments from 2012 to 2017.....	3
1.3 Number of available Wi-Fi location in selected countries as of 4 th quarter of 2013....	4
1.4 Location based services.....	5
1.5 Smartphone owners who have used location based services via smartphone, 2013- 2015.....	7
1.6 Map showing a track of mobile device measured with the help of GPS in an outdoor environment.....	8
1.7 Map showing a track of mobile device measured with the help of GPS in an indoor environment.....	9
4.1 GPS satellite around the world and the area of impact.....	23
4.2 Evolution of Smartphones.....	27
4.3 Marketshare of operating system in a mobile devices, 2017.....	30
4.4 COO method for localization.....	32
4.5 Calibration phase of fingerprinting method.....	34
4.6 Positioning phase of fingerprinting method.....	35
4.7 TOA Measurement in positioning.....	36
4.8 TDOA Measurement in positioning.....	37
4.9 AOA Measurement in positioning.....	38
5.1 Proposed framework of indoor user localization.....	42
5.2 Screenshot of Wi-Fi Fingerprinting application.....	43
5.3 Points of experimentation on a floor.....	44.
6.1 Error distance in each algorithm.....	46

List of Tables

2.1 List of different approaches taken by researchers.....	15
4.1 Comparison of positioning techniques.....	25
4.2 Functionalities of Smartphones and their key features.....	28
4.3 Comparison of different positioning techniques.....	35
6.1 Localization errors of fingerprinting algorithms.....	46

Chapter 1

Introduction

1.1 Background

Smartphones nowadays are equipped with more advance computing capabilities and connectivity than regular mobile phones the demand of such applications has led to major increase in their pressing requirement and supply. Smartphone shipments worldwide are projected to add up to 1.71 billion in 2020. By 2018 over a third of the world's population is projected to own a smart phone an estimated total of almost 2.53 billion smartphone users in the world [1]. With this steady development and rapid demand, it's integration into our daily lives is becoming deeper hence the requirement for personalized applications and assistance is getting popular and becoming a necessity. The dependency of the people on their smartphones have been increasing as they are the lone source of telecommunication, entertainment, social media, emails, messages etc in day to day life. Hence creating a huge area of interest and exaction for developers, researchers and innovators.

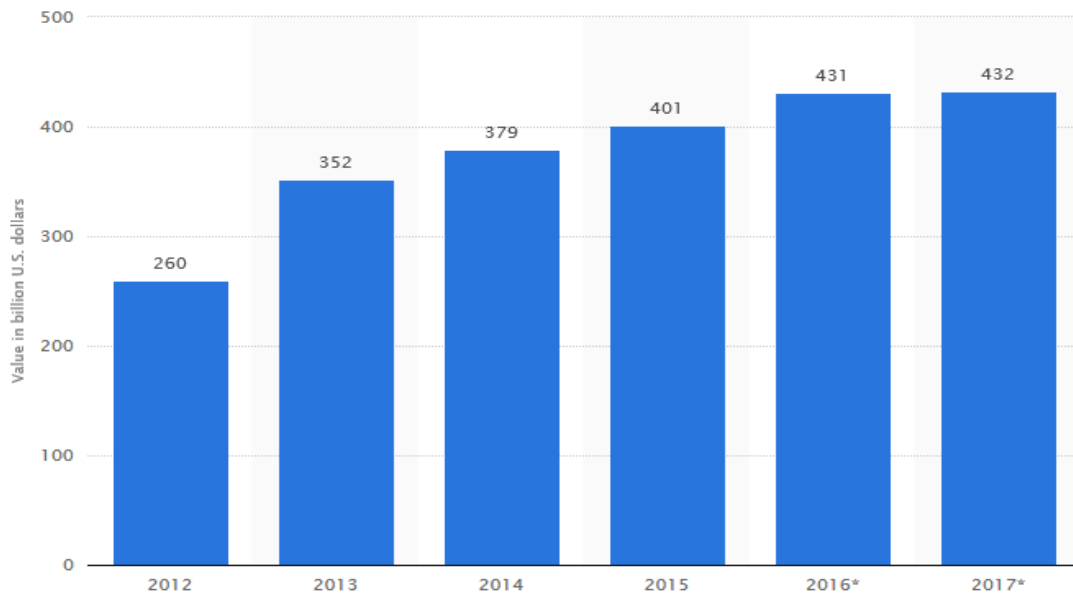


Figure 1.1 Global smartphone sales value from 2012 to 2017 [2].

Being an integral feature of all kinds of smart phone markets for several years Wi-Fi has been irreplaceable even in major companies like Apple, Samsung, Nokia, Motorola *etc.* As a matter of fact companies are nowadays marketing and differentiating on the basis of Wi-Fi capabilities of their devices. Resulting in a consequence where significant development can be seen in the technology and applications beholding wireless networks in Smartphones. To give this discussion an evidence we look into the developments of the WLAN market in the world today. Observing the statistics of it we see that the global Wi-Fi market size is expected to grow from USD 14.8 billion in 2015 to USD 33.6 billion in 2020 at an estimated compound annual growth rate of 17.8% from 2015 to 2020.

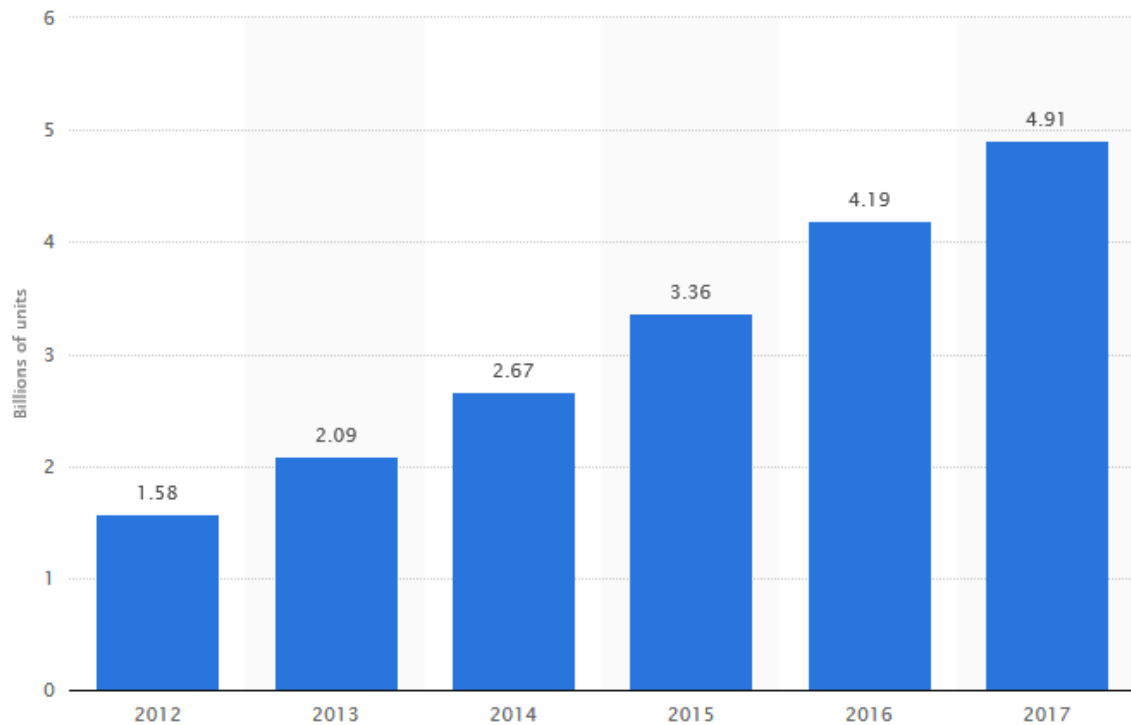


Figure 1.2 Global Wi-Fi enabled equipment shipments from 2012 to 2017 [3].

Mainly sensors are the ones that sweeps the smartphone market rather than processors. Sensors and processors gelled together is what makes a simple mobile phone smart. Various sensors like microphone, video camera, gyroscope, proximity sensor, accelerometer, GPS receiver, Bluetooth, digital compass, Wi-Fi *etc.* Popularity of these sensors has made use of fast communication, ever ready entertainment and location based services more widespread and their demand prevail. Among all of the above GPS is the first choice for fulfilling the need of locating a user's position, though its performances is disappointing in difficult circumstances like where coverage area is less or indoors. Thus leading to our and many more studies on indoor user positioning using built in sensors like Wi-Fi. Wi-Fi was initially designed to enhance the telecommunication and entertainment services but has eventually been used in various other applications. The extensive use of Wi-Fi has resulted in far reaching spread of WLAN in our environment. Which in turn has provided us with pervasive connectivity in our surroundings, specifically indoors to our smartphones. This has opened the doors to the research of user's positioning using our widespread WLAN network and

smartphones. The inability of GPS to work in indoor environment and availability of Wi-Fi network in abundance has lead to increasing interest for research and development in this area.

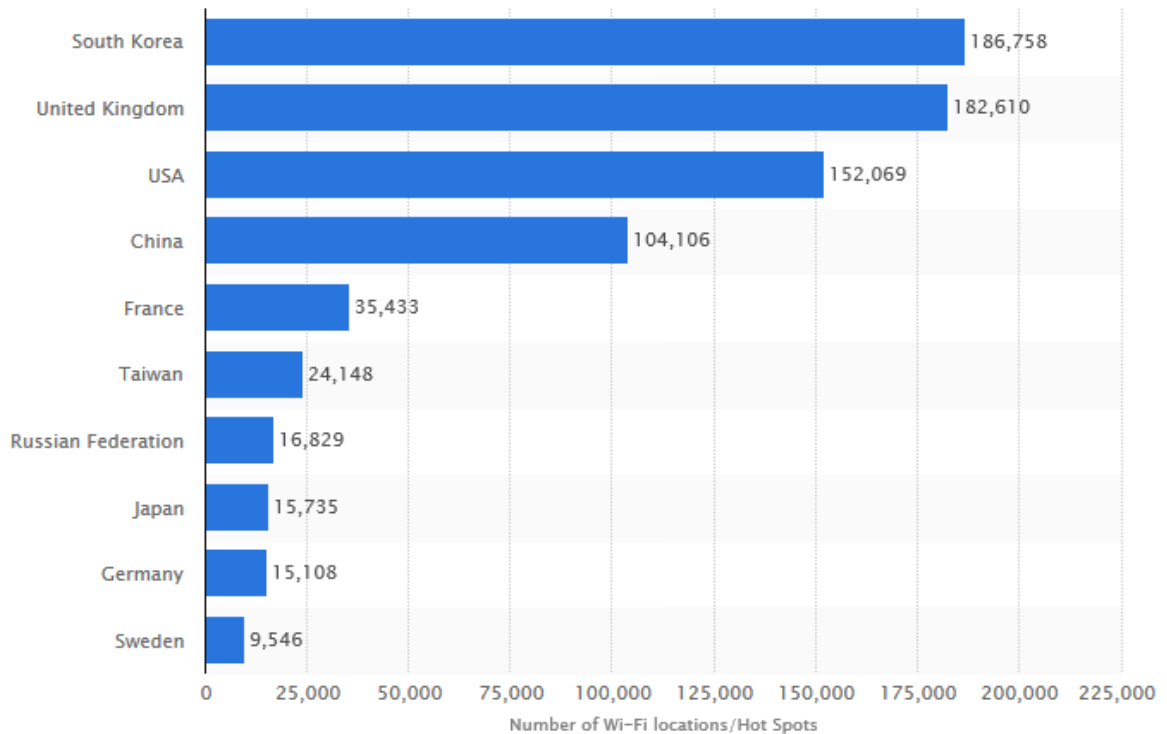


Figure 1.3 Number of available Wi-Fi locations in selected countries as of 4th quarter of 2013 [4].

1.2 Location based services and applications

The location of a mobile device known as localization which has become a vital requisite for a lot of people on a daily basis for a variety of supply and demand of application utility and services. Location based services deliver the information location of the mobile device in presentation to the user operating it and some other value added services to enhance the user's experience. Some of the services are illustrated in figure 1.4.

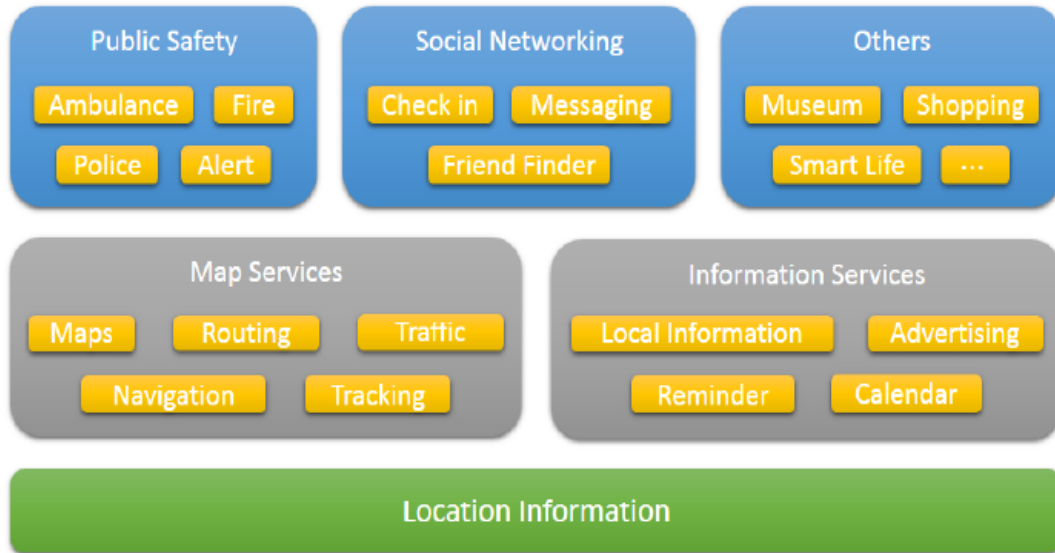


Figure 1.4. Location Based Services

Among all the services provided digital mapping has become the most widely used and accepted by the user. Does digital mapping has become the most element and crucial of all the services, resulting in the manufacturers putting it as an inbuilt application in most of the smartphones nowadays. Apart from basic entities like localization tracking routing and navigation it also provide us with applications like weather reports, consensus of the traffic ,food and beverages catering, location based reminders and other services with the help of any available local information.

Nevertheless, location based services helps the advertisement Agencies and content providers to hit the target audience according to the location which helps in listening the burden on resources, people, servers and many more. Search by Linking location based services with other services we are further spreading so many different branches of LBS.

Performances of emergency services like fire brigade, police and Medical Systems have improved over time because of the fact that the tracking and finding location of people have increased in accuracy that in turn face the time lag the service men previously had to face because of the unknown. Vehicle tracking is still one of the fast growing application. GPS equipped fleet vehicles, public Transportation system, delivery truck and Courier services is used to monitoring location at all times. Some of the commonly used

applications on the day-to-day basis are on road services, delivery or pick up management, taxi or employee pick up or drop services, security applications, long distance tracking, healthcare/ ambulance and others. The digital map also gives a detailed information like poll for locations, route selection and adherence, real time location of vehicles, detailed city maps and others.

Social networking combined with LBS is a very luring market in the field of application. With the development of high speed Internet services, smart devices and enhanced localization techniques, people online are becoming more and more in relevance with their location. Check ins in public places, finding friends in your area and others are becoming very popular and a growing with time.

According to new researches location intelligence is providing marketers information on consumer behavior, mobile marketing tactics and data quality. Localization services are helpful in keeping an eye on the integration level of LBS with other smartphone activities. According to reports if 67% of adult smartphone users you music streaming application to listen to music daily, 47% said they used video chat app and view their favorite TV series and movies on their commercial available subscription application but any contrary 90% of the users pointed out the user smartphone for navigation, recommendations and different information in accordance with their location. The changing number of users overtime using LBS can be seen in figure1.5 [5].

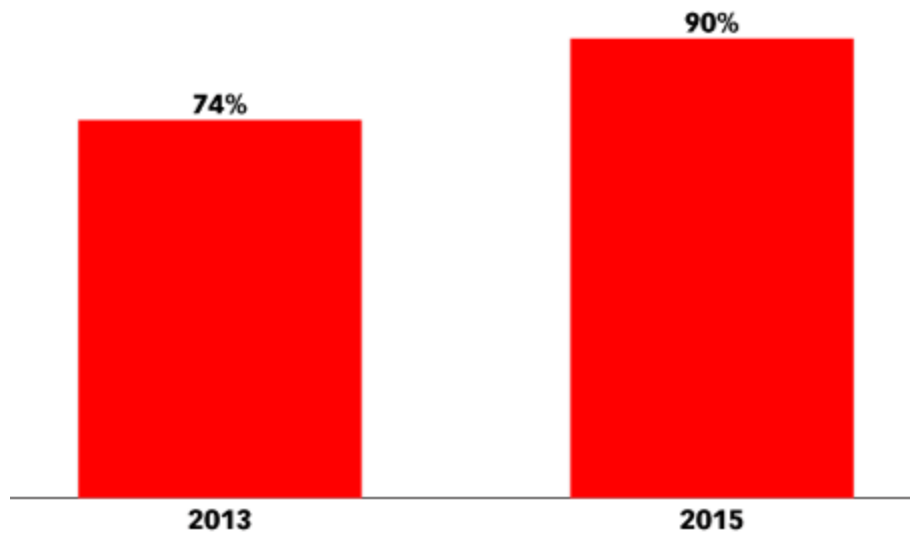


Figure 1.5. Smartphone owners who have used location based services via smartphone, 2013-2015

Find of such growth the LBS remains an emerging industry which are results of some major obstacles like inefficiency to achieve accuracy in Indo user localization. Statistical analysis that a common use proximity 80% to 90% indoors and it off data exchange, 70% off Cellular call originate from indoors. Services based on connection provided by the satellite based localization techniques like GPS has a poor reception in indoors which does not meet the requirements and demand of the market. With the research and enhancement of indoor positioning systems we will find more and more solution to the problem.

1.3 Indoor Localization Problem

An average person goes and stays at different places at different points of time on a daily basis. Now to satisfy the demand of localization various researches have tried to achieve it in every kind of environment possible. Expertise have been obtained with fairly good accuracy with the help of GNSS(global navigation satellite system). It uses a large group of satellite placed all around our planet giving us comprehensive coverage with decent

accuracy and ubiquity. The most popular and well known global Navigation satellite system is GPS (global positioning system) which is currently serving users all over the world with precision and in all kinds of weather conditions [6]. GPS uses at least 3 or more satellites to locate a user but sometimes the signal exchange between the user and the satellite is obstructed due to various environmental conditions.

Insufficiency in LOS (line of sight) makes it difficult for the GPS to receive signals from the user and vice versa in an indoor environment. The GPS signal received in an indoor environment in comparison to the out environment can be clearly seen in figure 1.6 and 1.7, which have been measured on the same device.

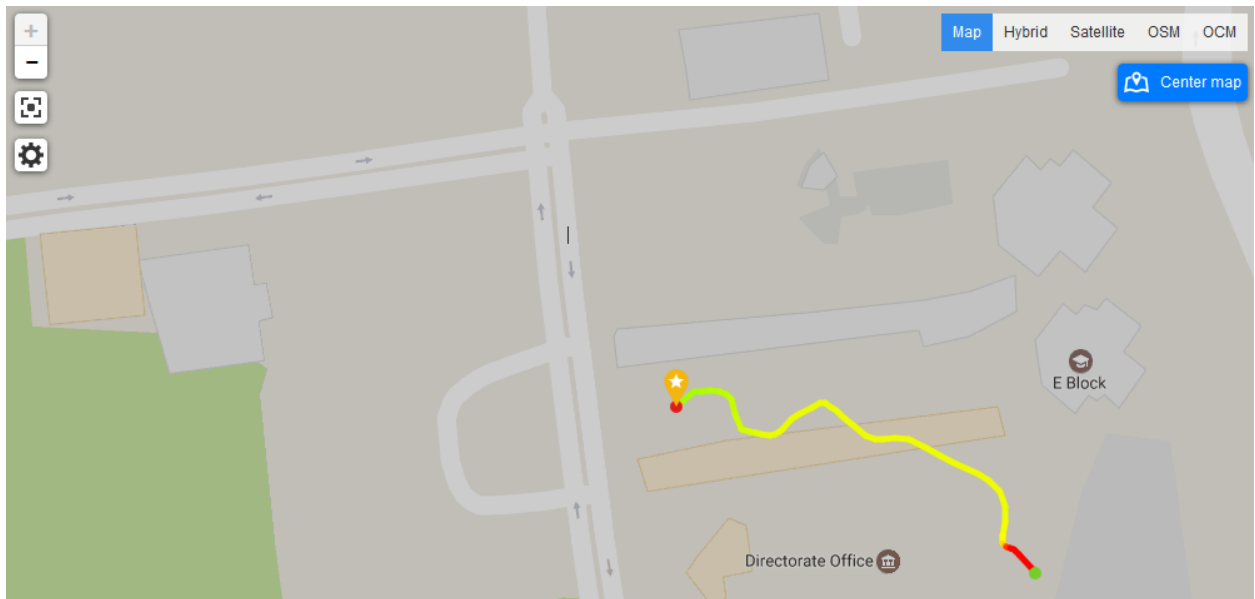


Figure 1.6. Map showing a track of a mobile device measured with the help of GPS in an outdoor environment

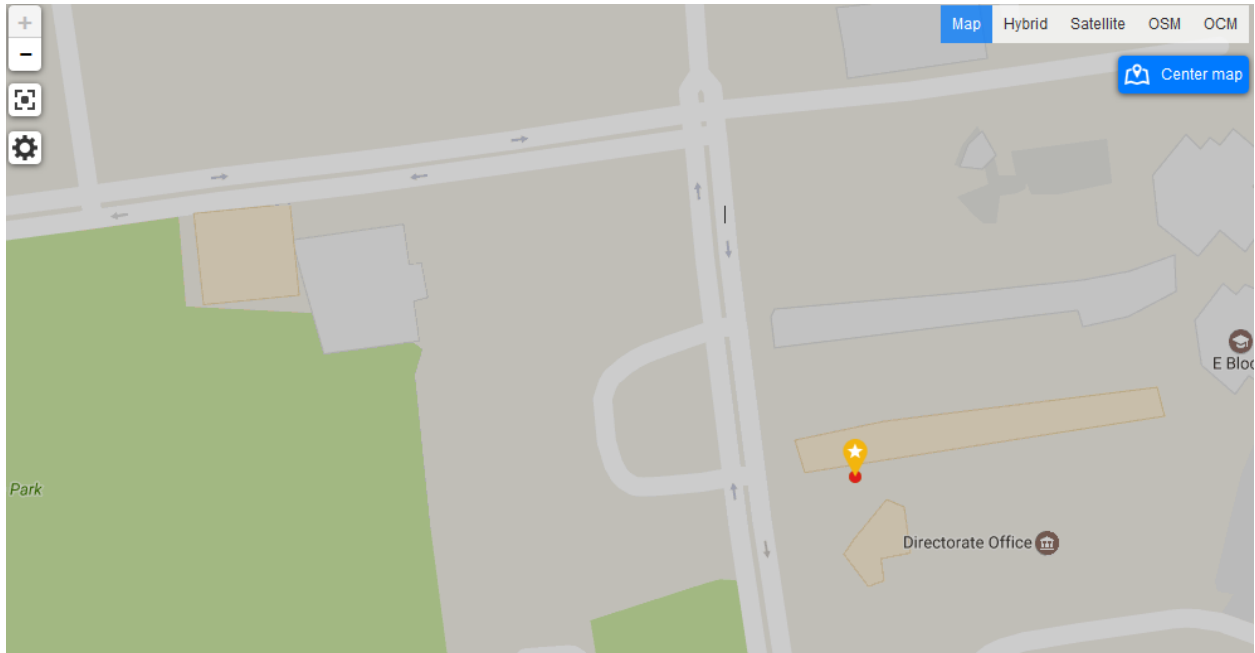


Figure 1.7. Map showing a track of a mobile device measured with the help of GPS in an indoor environment

Now we can clearly see the inability of a GPS to breach the walls of indoor environment, in spite of the movement of the mobile device there is none detected because of inability of the device to receive the signal from the satellite. Looking at the results, we start looking in other directions to fulfill our purpose, some of them are listed below:

- Positioning with the help of Beacon, that is measuring the signals on the basis of their physical quantities which changes when the position of the person changes.
- Positioning without beacons, which uses the widely known dead reckoning technique to detect a person's position with the help of mobile sensors.

Due to phenomena like multipath fading and shadowing present due to multiple obstacles like walls, furniture and others in an indoor environment, it is difficult to locate a user's location with the help of beacons. The receive signal is sometimes adulterated with non Line of Sight constituents. It intern disturb the time synchronization, thus messes up the system relying on time for positioning. Received signal strength is yet another measurable entity and is mostly used due to the fact that it's access is easy and feasible.

However RSS faces multipath fading in an indoor environment which is an unavoidable glitch and is commonplace. And thus the modeling of propagation of indoor signal is tedious as indoors are not as regular as outdoors. So models whose technique are based on the learning of the propagation of do not survive in indoor environment. As a physical aspect of an indoor area can change drastically from a big conference hall to the strait corridors of institutes, offices and homes. So even a minor addition for change in that environment like movement of people or furniture can jeopardize the free learnt path of propagation which in turn makes the model invalid in some cases.

However the positioning based on beacons that depends on census of the mobile device trace the user's location by regularly reckoning there displacement from where they started. Dead reckoning via sensors however cannot be the only answer of all the problems of indoor localization because of a number of shortcomings like, a starting point have to be always be known which is not the case all the time, at time low precision of sensors of the mobile and the integration of the signal received by the sensors and combining them into one accumulated result can end up in the final product having multiple errors.

However, to overcome this problem the hybrid localization techniques are being proposed with different kinds of frameworks combined with the best features and advantages of the technique and uses it too handle the shortcomings of each technique.

1.4 THESIS LAYOUT

This thesis is composed of 7 chapters. The path of the thesis goes from introduction about to the conclusion of the research. Chapter 1 gives you a brief idea of the stand of smart phones and Wlan networks in the market in the present scenario. It is introduced to give the idea of as to why these entities are an important part of this research. Chapter 2 is a literature survey of all the state of the art research on the topic. Chapter 3 constitutes the problem that is being solved, the aim and the objectives of this work. Chapter 4 chalks out the existing techniques and technologies of this area. Their performance in an indoor environment and how their equation with smartphone and fingerprinting techniques can

be optimized to obtain better results. This ends with an summary of existing methods and algorithms used for localization in the research.

The crux of the work done in this thesis is described in chapter 5, the layout of framework proposed in the research in discussed in detail, which consists of 3 phases each of which are discussed with the description of their functioning. The results obtained from the work done are shown and analyzed in chapter 6, with the conclusion of the wok and future scope discussed in chapter 7.

Chapter 2

Literature Survey

The circumstantial and ephemeral nature of user localization makes it as difficult as it is important to pin it from paper to plane. The wide expanding area of its applications makes it momentous, some of them that have already been worked upon will be discussed here briefly answering our that has risen during the course of this research.

2.1 Need of User Localization

Finding a user's location at the time of crisis with the help of radio frequency based system [7]. Determining the location of user at a time of emergency helps in getting the right amount of help in the niche of time. This work has really helped and worked in unknown buildings whose schematics are unknown or not available when required. Ondrej Krejcar was successful in bringing down the detection of a user's location in run time to a room granularity.

Positioning of people at the time of a natural calamity is a crucial area of research and Zorn et al. have come out with a technique which helps people stuck in bad conditions due to various environmental issues [8]. They have developed a system which uses the signal of the mobile devices of people and detects their location, field results of which are shown in their work. They have also proposed on building a platform for the same cause that can be easily accessible to the rescuers in the field.

During large scale gatherings it is very important to monitor the crowd to avoid any mishaps but this becomes a tedious task when the area of event is too large and the population of people attending the event is also very large, this in turn doubles the complexity of the situation which is what Blanke et al. have tried to monitor [9]. They collected a large amount of data at an big event in Russia where 56,000 people

downloaded their application and they got 25 million location updates which created a huge database for them and other researchers to study and work upon.

Although this is a great approach to fingerprint a crowd but not always a feasible one because of the requirement of a device on each individual so, Xi et al. have proposed a device free method that helps in crowd monitoring at a large scale [10]. They have presented us with Free Crowd Counting (FCC) approach that is done with the help of Channel State Information (CSI) of Orthogonal Frequency Division Multiplexing (OFDM) system.

Taking all the above scenarios in consideration a category still falls out of it , that of people with cognitive impairment. Those people whom we cannot rely upon following instructions to have a controlled environment. So, Chang et al. have used bluetooth tags with personal digital assistant (PDA) to help patients with less cognitive intelligence than an average person by helping them with pictures and videos of their route [11]. This has proven to be beneficial as the patients are always in an constraint confinement so the bluetooth signal is always in range and never lost as in the case of people going outdoors. We, see here that the responsive of the patients is higher in case of videos than pictures but sometimes it is a bit too fast for the user depending on the index of their impairment.

Apart from all this there is one more crucial use of positioning and that is security, Maruyama et al. have taken this problem into consideration and worked upon detecting trespassing in an given area [12]. They have used video footage of the area in question ,and then have detected a moving object in the view with respect to time. This is done by slitting the frames and applying image detection on every one of them. The proposed method is very useful for homes because of its simple configuration.

The most usual, high in demand and important reason behind localization of a user is for providing users with location based services. It has become a crucial part of our day to day life and provides us with ample amount of applications. The perks of having it and how it works in our daily scenario were first shown in this work [13].

2.2 Various Indoor Positioning Systems

There are various technologies that have been used to determine a user's position in an indoor area, and these have been compared with one another to determine the best results for the task in hand .It can be seen in this analysis that though the visible technologies give the best results but Wi-Fi gives the better result where there is no line of sight [14]. Some of the work shows collaboration of these techniques to yield a better result [15].

Such as by combining results of Wi-Fi fingerprinting with magnetic fingerprinting, visuals obtained through camera and co-occurrences. The top results of Wi-Fi fingerprinting are picked and confirmed with previous history of visuals and then are further narrowed down by magnetic fingerprinting and co-occurrences [16] [17]. Some of these studies has even involved hardware for detection of people or objects in an indoor environment, but cost is one of the major factors involved in such scenarios to make them feasible and attainable, Therefore using RFID sense-a-tag as these tags are low in cost and are power efficient, the result obtained from these tags are further processed through computer simulation and is refined [18].

Contrary to this sometimes the requirement is to obtain a highly accurate localization regardless of the cost of the hardware and the infrastructure used, to fulfill such demands mobile application frameworks are used to connect with previously provided devices in a specific area over Bluetooth and analyze the data obtained with circumstantial evidence and algorithms [19].

Whereas in some cases various algorithms and models are tested and used to determine the location .the use of OS-ELM (online sequential extreme machine learning) is one such case .This algorithm is used to trace the data in real time and move along with the changing dynamics of the environment thus resulting in location reorganization with high accuracy [20].

2.3 Previous Work

A lot of researchers have been working on indoor user localization using Wi-Fi by using different techniques. Some these techniques are like how Rohra et al. collected a large amount of data using positioning and then applied hybrid algorithm on it to achieve desired result. They used neural network and the weights used in these were obtained by fuzzy hybrid of gravitational search algorithm and particle swarm optimization [21], which in turn improves the classification rate .

By combining text to talk system with Wi-Fi positioning Hub et all, used flash lights and sensor modules to collect the environmental data. This data is then processed by sending to servers , as a result it gives information about navigation, object characteristics, orientation and position of the surroundings which are then finally conveyed to the user[22].

GPS does not work or is recommended for localization when the environment in which user is to stay keep on switching. So, Rekimoto et al. researched in a busy metro city as to whether the signal to Wi-Fi networks from different locations and collected a data from more than half a million distinctive access points [23]. It has proven to be very useful for life logging purposes described in the work.

Some other recent work of researchers can also be seen in table 2.1 listed below.

Table 2.1 List of different approaches taken by researchers

S.No.	Title	Year	Author	Approach
1.	Pallas: Self-bootstrapping fine-grained passive indoor localization using WiFi monitors	2017	Luo, Chengwen, Long Cheng, Mun Choon Chan, Yu Gu, Jianqiang Li, and Zhong Ming	Pattern analysis and Bootstrapping

2.	SDR based indoor localization using ambient WiFi and GSM signals	2017	Nambiar, Varun, Edwin Vattapparamban, Ali I. Yurekli, İsmail Güvenç, Mohammad Mozaffari, and Walid Saad.	Software defined radios with Wi-Fi and GSM
3.	CSI-based fingerprinting for indoor localization: A deep learning approach	2017	Wang, Xuyu, Lingjun Gao, Shiwen Mao, and Santosh Pandey. "CSI-based fingerprinting for indoor localization	Deep learning
4.	Accurate indoor localization and tracking using mobile phone inertial sensors, WiFi and iBeacon	2017	Zou, Han, Zhenghua Chen, Hao Jiang, Lihua Xie, and Costas Spanos	Multiple hardware detection
5.	Improving indoor localization using bluetooth low energy beacons	2016	Kriz, Pavel, Filip Maly, and Tomas Kozel	Bluetooth beacons
6.	Tightly-coupled integration of WiFi and MEMS sensors on handheld devices for indoor pedestrian navigation	2016	Zhuang, Yuan, and Naser El-Sheimy	Combination of Wi-Fi and MEMS
7.	Where am i in the dark: Exploring active transfer learning on the use of indoor localization based on thermal imaging	2016	Lu, Guoyu, Yan Yan, Li Ren, Philip Saponaro, Nicu Sebe, and Chandra Kambhamettu	Thermal imaging
8.	A hybrid WiFi/magnetic matching/PDR approach for indoor navigation with smartphone sensors	2016	Li, You, Yuan Zhuang, Haiyu Lan, Qifan Zhou, Xiaoji Niu, and Naser El-Sheimy	Integration of Wi-Fi, magnetic matching, PDR
9.	Fusion of WiFi, smartphone sensors	2015	Chen, Zhenghua, Han	Kalman filter

	and landmarks using the Kalman filter for indoor localization		Zou, Hao Jiang, Qingchang Zhu, Yeng Chai Soh, and Lihua Xie	
10.	ZIL : An energy-efficient indoor localization system using ZigBee radio to detect WiFi fingerprints	2015	Niu, Jianwei, Bowei Wang, Lei Shu, Trung Q. Duong, and Yuanfang Chen.	ZigBee radio
11.	A fuzzy logic-based system for indoor localization using WiFi in ambient intelligent environments	2013	Garcia-Valverde, Teresa, Alberto Garcia-Sola, Hani Hagra, James A. Dooley, Victor Callaghan, and Juan A. Botia	Fuzzy Logic
12.	FM-based indoor localization	2012	Chen, Yin, Dimitrios Lymberopoulos, Jie Liu, and Bodhi Priyantha.	FM
13.	Precise indoor localization using PHY layer information	2011	Sen, Souvik, Romit Roy Choudhury, Bozidar Radunovic, and Tom Minka	PHY layer information
14.	Indoor localization using improved RSS-based lateration methods	2009	Yang, Jie, and Yingying Chen	Lateration method
15.	Redpin-adaptive, zero-configuration indoor localization through user collaboration	2008	Bolliger, Philipp	Integration of Wi-Fi and digital compass
16.	A real-time indoor Wi-Fi localization system utilizing smart antennas	2007	Lim, Chin-Heng, Yahong Wan, Boon-Poh Ng, and Chong-Meng Samson See	Smart antenna

Chapter 3

Research Problem

GPS is a crucial technique to detect a user's position outdoor but, due to attenuation of its signal by hindrances like walls, doors and other objects, it loses its strength and we are unable to get satisfactory results indoors. Several techniques which can be hardware and software oriented are used for user positioning indoors but extra cost and the sheer need of installing these hardware and software in our daily life can be cumbersome leading to unwillingness of users to use them to detect objects and measure distances.

3.1 Problem Statement

In the past few years, GPS has been widely used in outdoor positioning and tracking in our daily life (e.g. GPS in-car navigation systems). However, for indoor environments, it is well known that GPS does not work well since walls, floors and other construction objects can greatly attenuate or even block satellite signals. Several alternative techniques such as Assisted-GPS (A-GPS), Bluetooth, WLAN, Zigbee and Radio Frequency Identifier (RFID) etc. have been proposed for indoor positioning and tracking.

In this research, an efficient indoor positioning system based on the IEEE 802.11 wireless technique will be investigated. The Received Signal Strength (RSS) fingerprinting method in particular will be studied and smartphones, which have WLAN hardware requirements and limited power, memory and computation capabilities, will be used as mobile devices. Many technical challenges are faced during the deployment of application which determines RSS on smart phones. The wavering nature of RSS in an indoor environment makes it highly unstable. Some of the factors effecting it are walls, metal objects, furniture *etc.* The signal experience multipath and fading effects due to these obstructions which results in two different readings at the same position or same reading at two different positions. And WLAN network has a limited range of 2.4 GHz

public bands which is shared by a lot of devices at the same time. Radio interference during the accumulation of RSS database most of the times result in unstable readings. In fact, interference of human body with the signal also alters its trajectory and gives fluctuating readings as it contains 70% of water. If a person comes between the line of sight of access point and the receiver the readings get hindered. The orientation of the device while receiving the signals also alters it as, angle of receiving is important in such scenarios. To overcome such issues fingerprinting is taken into account to establish a relation between position of the user and RSS.

Now , our main challenge here resolute to multipath effect where two different position shows the same RSS strength. So to overcome this dilemma we turn towards image recognition methods which can resolve this issue.

3.2 Research Gaps

Some of the gaps discovered during the course of this work are listed below:

- The method of Wi-Fi fingerprinting bares a drawback of fingerprint ambiguity in the hands of multipath fading and temporal dynamics.
- Additional hardware requirements increasing the performance but, in turn divesting availability to the masses.

3.3 Research Objectives

The main objectives of the work are :

- To study and use the existing available techniques of Wi-Fi fingerprinting with the help of a commercially available application.
- To develop a dense database using off the shelf open source application.
- To clean the data and making it efficient to train machine learning algorithms.
- To estimate a user's location based on machine learning algorithms and compare their performance based on accuracy obtained.
- To collect image database for every point of user positing estimation.

- To estimate a user's positioning in a certain area using image evaluation, on an open source off the shelf image evaluation software.
- To put the results obtained in the pipelined framework and test its performance based on accuracy obtained.

Overview of Existing Localisation Technique

Various localization techniques are used to determine the position of users or mobile device nowadays, does wearing the rules of accuracy. The one that is used most widely is GPS, that gives us both low accuracy and high accuracy localization capabilities relying on the system used (i.e., type of receiver). The performance of GPS in an outdoor environment is relatively better than its indoor counterpart because of physical obstruction present in an indoor environment. There are different positioning systems present for indoor localization among which localization with Wi-Fi has gained increasing popularity in spite of its shortcomings. The following chapter shed some light on some significant positioning Technologies and overview there elemental behavior, requirements, advantages and disadvantages and their accuracy based on positioning.

It is to be seen as follows, typical positioning technologies are being introduced in section 2.1. Section 2.2 encapsulates the challenge faced by positioning system based on Wi-Fi in an indoor environment. Thus to evaluate these Technologies on a smartphone, localization technologies are compared in section 2.3. In section 2.4 the ways present to measure the above Technologies namely RSS based localization, time difference of arrival(TDoA), time of arrival(ToA) and angle of arrival(AoA) are presented. Fingerprinting done on Wi-Fi based positioning system are chosen and different methods used to obtain outcome based on this method are compared in section 2.6.

4.1 Positioning Techniques

Many position techniques are used in various environment according to their requirements and to achieve the best results possible. Though, the types of environment are mainly divided into two categories indoor and outdoor environment where a positioning system is largely required, all other categories can be set categorized under these two. So, for outdoor environment we have seen that GPS works out to be the best as it can provide us with high accuracy and availability at most times. However, its major drawback is its incompatibility of breaching physical obstruction in an indoor

environment. Therefore we had to look in a different direction to achieve positioning in different environment successfully. Few of such techniques are discussed below.

4.1.1 GPS

There are 2271 manmade satellites orbiting around a planet 24 out of which forms the GPS satellites constellation. The satellites orbiting around the earth in 6 major earth centered orbital plane and each Orbit can constitute up to 30 satellites. The initial objective to set up the satellite in space was for military navigation but then it was made open for public use. As we know that GPS is the most widely used Technology for tracking and navigation, so different types of GPS receivers are available to us in the market. For example, to obtain high accuracy localization use of geodetic surveys and also Engineering surveys are done, these are being used taking an accuracy of millimeter and centimeter into consideration. GPS is a very good selection taking into account its advantages as compared to its other counterparts. It is considered as a primary tool among common mass for fulfillment of requirement life navigation, tracking and positioning purposes. Smartphone nowadays are coming with inbuilt GPS receiver that shows its popularity and demand.

To determine a 2D position of a person that is the information of latitudes and longitudes of the place where a person is standing we need at least 3 satellites. But to obtain a 3D position of the same place that is latitude, longitude and altitude we need more than 4 or more satellites to determine it. Once the GPS signal is received by the user and his or her position is determined, the further features of the application like distance to destination, trip distance, current speed, track *etc* are determined. A major advantage of GPS is its availability at all times. Figure 2.1 all the major satellites rotating around the earth in their orbits and the area of impact [24].

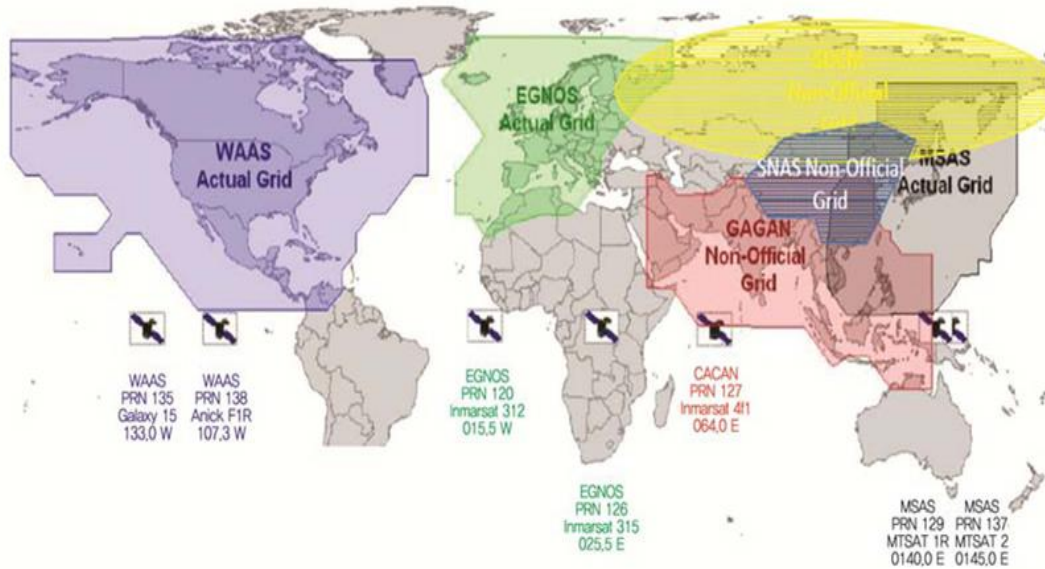


Figure 4.1 GPS satellites around the world and their area of impact

4.1.2 A-GPS System

A-GPS and enhance version of GPS which takes additional information from a cellular network to achieve better results it is done in the following ways:

- Rather than downloading location and information of satellites directly from the satellite it is done through a cellular network to improve the speed of the time of first fix (TTFF).
- The inability of GPS to receive signals inside buildings and other concrete structures is overcome by calculating positioning using proximity cellular towers.

4.1.3 Wi-Fi based system

Wi-Fi is now becoming a largely accepted and Use technology for positioning because of the increasing availability of the Wi-Fi infrastructure its accuracy of positioning is also increasing with it. The fundamentals of WiFi positioning system somewhat to run in parallel with the cell ID system.

The most advanced of the positioning system that use Wi-Fi also use the fingerprinting method [25], in which the signal strength of WiFi is noted from different access points in

the required area of analyzation. The noted observation are then accumulated in the form of a database and the actual positioning task is carried out afterwards. The positioning is done by comparing the measurement of RSS with previously obtained input. The position of access points do not change in regards to the infrastructure and is already known, so the results are obtained in respect to that.

4.1.4 INS (Inertial Navigation System)

Compasses, accelerometer and gyroscopes all of these or some combined are used in INS for the measurement of displacement from the starting point, velocity and orientation which makes it a self sufficient positioning technique [26]. The low cost of gyroscope and accelerometer chips increases their potential in becoming major tools of indoor positioning.

But there shortcomings due to drifting and bias make it difficult to distinguish them from navigation signals.[27]. A typical inertial measurement unit measures linear acceleration and velocity using 3 orthogonal gyroscopes and accelerometers.

4.1.5 Other Systems

Systems like RFID (radio frequency identification), bluetooth, ultrasonic and infrared also analyzed to see the mark of their potential capabilities and use. If one needs a wireless communication with in a short range and that consumes less power than one should go for Bluetooth [28]. RFID uses radio waves to transmit information in the form of unique serial number that is to identify a person or a mobile device. For a device to use infrared it's sensor has to be embedded in it, thus it can only be used within a small area and it cannot be used to communicate via walls and other physical obstacles.

Bluetooth, infrared and RFID have been previously used smartphones but due to a decline in the popularity they are being removed slowly from the hardware of the mobile devices. Ultrasonic devices are also used to project where the user is and determine the

distance. Though being a good medium of communication all of the above discussed technology can only be used in short range distance.

4.1.6 Comparison of Positioning Methods

The fundamental characteristics, accuracy, disadvantage and advantage of the previously discussed localization techniques are being compared in table 4.1.

Table 4.1. Comparison of Positioning Techniques

Positioning Technique	Range	Accuracy	Pros and Cons
Cellular Networks	1 km	Poor	Infrastructure not required Does not perform well in low signal conditions
Wi-Fi Positioning	10 - 100 m	Good	Works well in indoor environment even with no LOS Expensive hardware requirement with limited coverage
INS	10 m (2nm position error per hour)	Good	Cheap Drifting and bias
A-GPS	10 m	Excellent	More reliable Additional network assistance required
GPS	10 m	Excellent	High accuracy Line of sight required

The high accuracy of GPS has made it the most suitable technique to provide us with position information. Is one of the server side component then it makes it A-GPS. But both of them suffer with the same line of sight problem this only can be successfully used in outdoor environment. The Wi-Fi and overcome this issue by providing us with medium accuracy in an indoor environment. But, the high cost of hardware requirement and setup of wiper makes its own constitution and INS has its own drawbacks of heavy multiple error occurring during accumulation of received information.

4.2 Positioning with Smartphones

Smartphones are a major part of this results of the following section discusses them in detail. These are mobile devices with reasonably high functioning operating system with advanced sensors and with high connectivity responses. They are also known as miniaturized mobile computers as their functioning resembles desktop computers and laptops in several ways.

There are various sensors that come in built in the smartphones for different functioning as per the requirement of the market. To make multi use of the already present tenses in the smartphones location based service application make use of these nowadays, which make it an important device for indoor positioning system. GPS technology used in smartphones and is well integrated in it for positioning but because of its inability to perform indoor , the burden of indoor positioning release on other built in sensors.

4.2.1 Smartphone Evolution

Smartphones were even present to decades before what we see today though they were not called as smartphones then. The demand and technology of Smartphones has increased in an unimaginable way in recent years. The evolution of Smartphones in all these years is depicted in summaries form in figure 2.2 [29].



Figure 4.2 Evolution of Smart phones

4.2.2 Leading Functionalities of Smart phones

The integration of fundamental functionalities of a personal digital assistant (PDA) and mobile device led to the making of first generation of Smartphones. As the change in demand increased more and more different functionalities were added to the smartphones to make them more equipped to fulfill the demands of the users, the functionalities are listed in table 4.2.

Table 4.2 Functionalities of smart phones and their key features

Functionalities	Main Features
Video Camera	With two or more individual camera at front and rear positions, these can capture anything from videos, pictures, wide angle pictures, slow motion videos <i>etc.</i>
Media Player	With the availability of different types of media in the market these media players are capable of playing music and video in a wide variety of formats.
Applications	To acquire different external functionalities, a large amount of applications are available in the market which can be downloaded easily.
Touch Screen	With the development in multi touch sensors there is a both large and small touch screen available in the market as per the requirement of the user.
Web Browser	With the available mobile version of different sites it can also Run full html versions of different web pages.
Wi-Fi	With the embedded hardware for Wi-Fi sensors in the mobile devices it can catch the signal of WiFi network and even Hotspots.
GPS	GPS in Association with the map application is an inbuilt feature of most of the smartphones nowadays.
E-mail	IMAP or POP3 best feature connectivity that can be found in desktop computers can also easily be done in mobile devices.
3G	It is the 3rd generation of high speed network connectivity with the 4th generation also available in new models coming fresh in the market.
File Storage	With a large amount of functionalities and content available in your phone just a touch away mobile devices come equipped with large amount of internal storage and with the availability of extending that storage with the help of micro SD card.
Standard Feature	Applications like calendar, contacts, bluetooth, SMS/MMS,

	changing themes <i>etc</i> are available before hand in the mobile devices generally.
--	---

4.2.3 Operating Systems in Smart phones

Operating system is what makes or breaks a smartphone with the popularity of their functionality and features many operating systems have and are becoming more and more popular which, in turn is spreading the awareness among the user base about them. From providing numerable features for user satisfaction to giving a large platform of software based application to the user, each operating system has its own customer base who's needs fit to the functionalities provided by that particular operating system.

Operating system that covers a large amount of mobile phone market are Android, Windows, Blackberry OS, AppleiOS and Nokia Symbian. With new innovations coming into the market everyday the versions of operating system gets updated regularly. Providing users with the option of not changing the hardware every time a version of operating system get released but to update of the software within the phone with same hardware. Which enhances the functionalities of the phone from time to time. this also helps companies to make hardware of the mobile phones which are durable as per the demand of the user, which in turn has saved the mobile devices hardware market from commercialisation. So this capability of a smartphone extend its shelf life. Share of various operating system in the market can be seen in figure 4.3 [30].

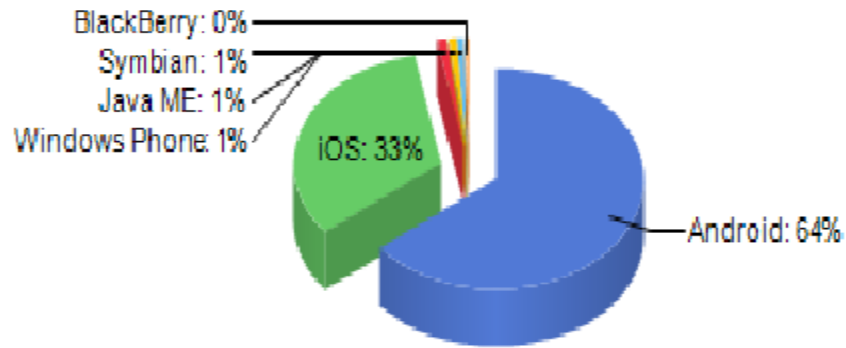


Figure 4.3 Market Share of Operating Systems in mobile devices, 2017

4.2.4 Sensors in Smartphones

Nowadays various type of sensors like accelerometer gyroscope WiFi and GPS receiver and bluetooth can be found in built in mobile devices. These devices use their sensors alone or in combination to obtain the desired result for location based services. Some of these are discussed below:

GPS Receiver

Positioning is a functionality that forms of base of many other functionalities in smartphones so, smartphones nowadays are equipped with high sensitivity GPS modules. For example, A-GPS and GLONASS(Globalnaya Navigazionnaya Sputnikovaya Sistema).GLONASS is a Russian version of GPS, it acts as an alternative to the GPS in case of something goes down so that the user doesn't lose its connectivity and it also provides a fairly good amount of precision. It is a second most widely used navigation system after GPS with range of accuracy is around 4.5 - 7.5 m with a fleet of total 27 satellites.

Sometimes the receivers present in mobile devices are navigation system specific but nowadays mostly coming with a combined backup connectivity to provide the users with better results. There are many interfaces and applications built for making the use of this feature easily accessible.

Cellular and Wireless network receivers

The smart phones available to us nowadays generally support cellular networks and WLAN. Cellular network comprises of an asymmetric radio network with transceivers maintaining the signals within them, the mobile picks up the signals from this network with the range of the transceiver. A wireless connection (radio) of the mobile device transceiver with the local area network (LAN) is WLAN. When a wireless communication is required that is within a short range and secure then Bluetooth is used. It has a short wavelength band ranging from 2.4 – 2.48 Hz [31].

Inertial Sensors

Inertial sensors basically includes gyroscopes and accelerometer. Accelerometer gives us the speed at which the user is on the move and gyroscope measures the angle angular rate. In contrast with the inertial sensors, nowadays Micro Electro mechanical Systems (MEMS) are being used as they consume less energy, is cheap, smaller as compared to inertial sensors and high reliability.

Microsensors have enabled the the devices to perform better, which is making research on this topic with help of mobile devices more popular, better in performance and more feasible.

4.3 Estimation Methods of Indoor Localization

Fingerprinting and Trilateration are the two effective ways of localization when done with the help of Wi-Fi technology. Following are the estimation methods used with them:

4.3.1 Cell of Origin (COO)

It is a network used to locate mobile devices. It works on the fact that a mobile device uses cellular network for communication and for localization, as is used in [33].size of cells in the network decide the level of its performance and accuracy. In a large urban network it can vary from 100-1000 meters which is the direct indicator of the accuracy in that area.

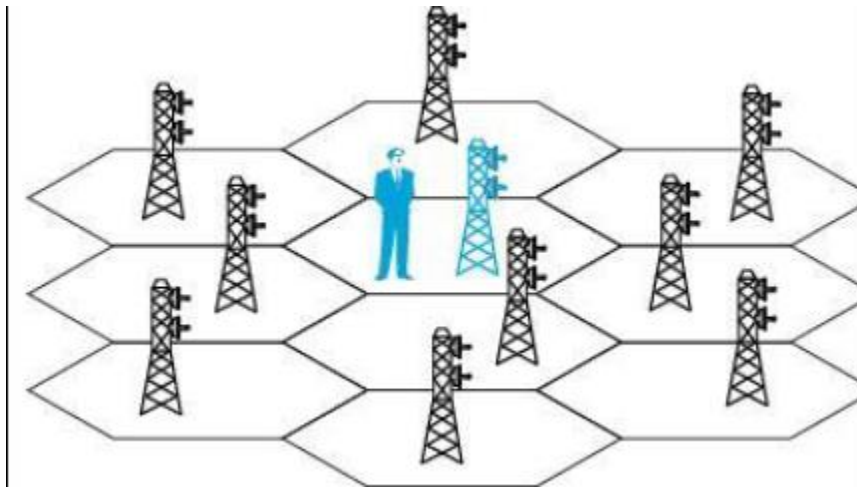


Figure 4.4 COO method for localization

The concept of COO can be crucial for indoor positioning, as it uses the similar algorithm to find a mobile device in a network as it does in cellular network. Here a cell is treated as an access point . it is a very fast technique of localization as it does not require any complex algorithm.COo positioning technique can be adopted in almost all cellular and WLAN based systems. Though the main drawback of this technique is coarse granularity, a user can be associated with a cell which is far from being physically close to user.

4.3.2 Trilateration

The method of positioning in trilateration is that it measures its distance from three known points also known as coordinates. This method of positioning is very popular and is also used in 2D positioning purposes where the coordinates are the satellites. In trilateration the coordinates are the access points whose positions are stored beforehand in a database and a comparative analysis is done with rest to the coordinates. This database consists of the access point position and also there MAC addresses. The average signal strength from each access point is noted and thus the positioning is estimated.

Signal attenuation is one major drawback of this technique, as the signal is getting affected by a number of obstacles such as walls, furniture, objects *etc.* Since the frequency used is same that of 802.11b that is 2.4GHz, therefore many devices take up its space and cause signal attenuation. Movement of people, orientation of antenna is some other factors that affect the signal strength. Accuracy of the estimation is largely affected with the quality of the signal received. This can be clearly seen in [34], where signal excess affects the accuracy.

4.3.3 Fingerprinting

Fingerprinting is the process of mapping a user's location with the help of their personal devices on which Wi-Fi is enabled. The RSS (Received Signal Strength) from various WAP (Wi-Fi access points) are measured and from this data the latitude and longitudes of the user's location are estimated. This method works for both indoor and outdoor locations where Wi-Fi is enabled. Fingerprinting can be majorly divided into two parts first is the calibration phase and then the positioning phase. In calibration phase the location of the reference points are stored in a database beforehand that can be seen in figure 4.5. The user's location data of a certain area is gathered beforehand for training purposes and then the testing is done based on information gained while training.

But, due to the wavering nature of the scenario we are working in the parameters on which we are dependent on to predict the outcome may change, like change in the

number of access points ,change in the number of smart phones or their types, change in the number of users in the area. Such variability in the environment affects the results negatively and increases the error quotient in the result. So, to enhance the outcome appropriate assortment of algorithms and parameters have to be done to attain maximum output. As compared to ToA and AoA this technique is more reliable as it can handle problems like multipath effect and no line of sight. The workflow of the positioning phase can be shown in figure4.6.

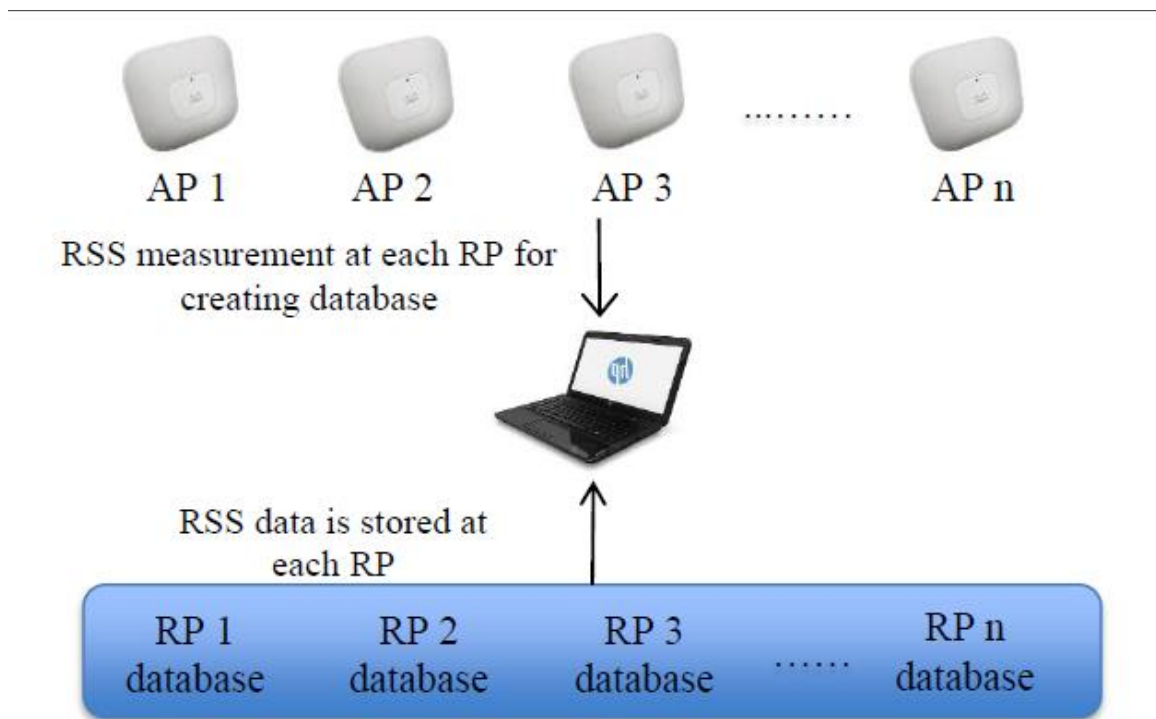


Figure 4.5 Calibration phase of fingerprinting method

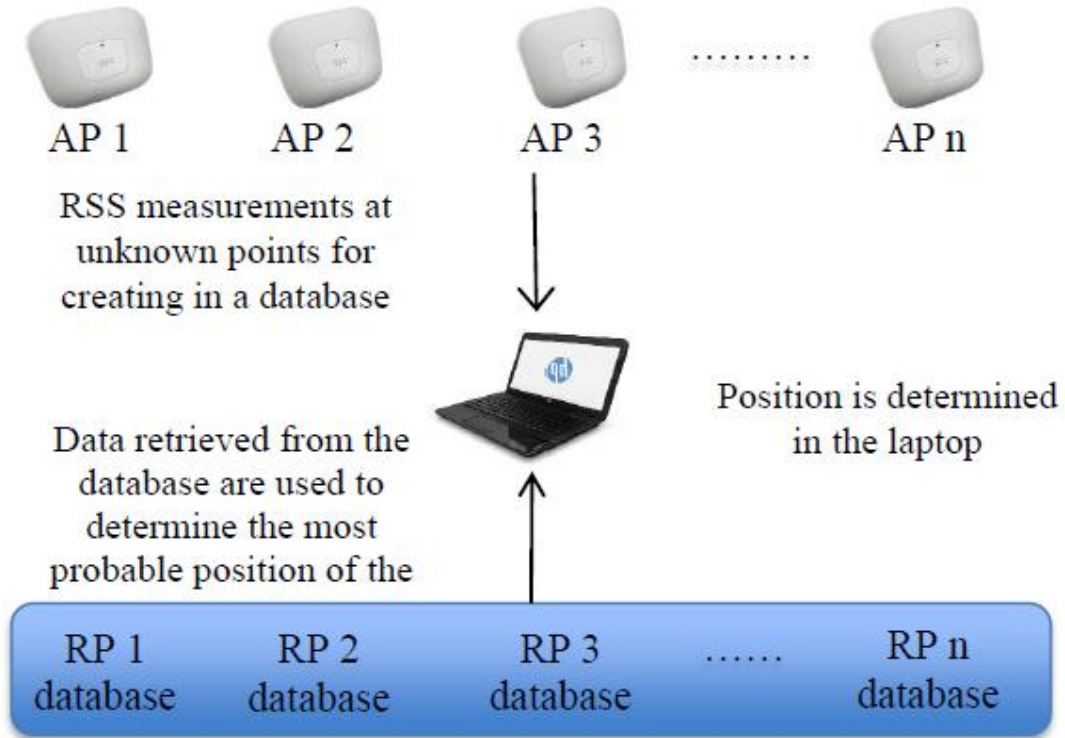


Figure 4.6 Positioning phase of fingerprinting method

4.3.4 Comparison of Positioning Techniques

By looking at the fundamental behavior and functioning of COO, Trilateration and Fingerprinting we can see fingerprinting is above the other two in performance. Their advantages, disadvantages and performance have been compared in table 4.3.

Table 4.3 Comparison of Different Positioning Techniques

Technique	Accuracy	Advantage	Disadvantage
COO	Low – Medium	Simple implementation	Accuracy is directly proportional to size of the cell and number of devices within a cell.
Fingerprinting	High	Training phase takes	Does not work well in

		care of most of the environmental issues	dynamic environment
Trilateration	Medium	No training phase required	Availability of at least three receivers at any point of time is a must.

4.4 Measurement Criteria of Positioning

Many types of measurement criteria and methods are used for positioning purposes of mobile devices .some f them are listed below:

4.4.1 Time of Arrival (TOA)

As we know that electromagnetic signals propagate at a constant speed. So if we know the location of the access point we can calculate the position of the receiver by noting down the time taken for the signal to travel from the access point to the receiver and knowing the speed of the signal. This can be done with the help of trilateration, we need readings of transmission signal from more than two access points. The mechanism of it is shown in figure 4.7.

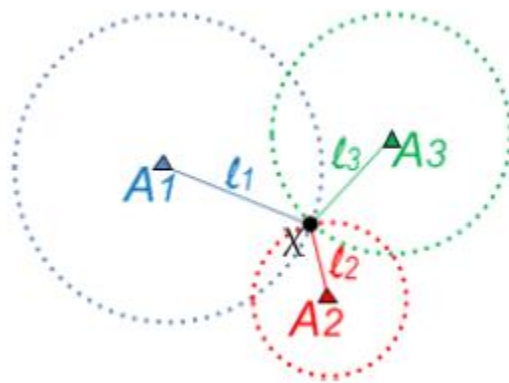


Figure 4.7 TOA measurement in positioning

Here we can see that X in the position of the user, $A1, A2$ and $A3$ are the position of the access points known beforehand. Also $l1, l2$, and $l3$ are the distances of user from the three access points respectively. The distance is calculated by:

$$l = C \cdot t \tag{4.1}$$

Where C is the speed of the signal and t is the time taken by it.

Synchronization of time is very crucial in TOA and is its major limitation also if not taken seriously.

4.4.2 Time Difference of Arrival (TDOA)

As we saw before in TOA the distance is calculated by knowing distances from three different distances from three different access points. But here we calculate the it by comparing the time of arrival from three different bases. The strength of the signal received from atleast three base station is used to estimate the position as shown in figure 4.8.

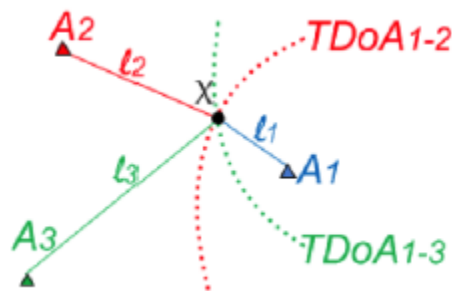


Figure 4.8 TDOA measurement in positioning

Here we can see that X in the position of the user, $A1, A2$ and $A3$ are the position of the access points known beforehand. Also $l1, l2$, and $l3$ are the distances of user from the three access points respectively. $TDOA_{1-2}$ and $TDOA_{1-3}$ are two hyperbolic curves with range difference as constant. The equation of the hyperboloid is shown below:

$$\text{TDOA}_{1-n} = |t_1 - t_n| = k_{1n} \quad (4.2)$$

$$|l_1 - l_n| = C \cdot k_{1n} \quad (4.3)$$

Here n is the number of access points, t is the time taken and k is TDOA constant.

TDOA is majorly affected by multipath errors due to interference, noise and propagation and also needs an accurate clock. High cost of equipment involved is also a setback of it.

4.4.3 Angle of Arrival (AOA)

The angle between the direction of propagation and reference direction is known as the angle of arrival. The angle of the reference direction is known beforehand and AOA is measured with respect to that [35]. As it can be seen in figure 4.9 AOA uses angular measurement from access point A_1 and A_2 to determine the location of the user X . this information is then send to the mobile switch and analyzed there for positioning.

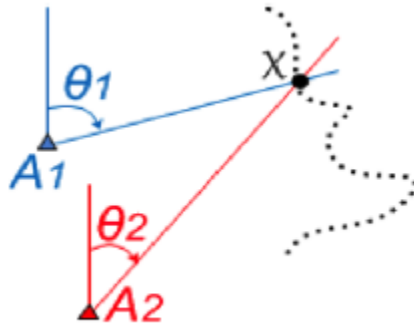


Figure 4.9 AOA Measurement for Positioning

The formula used for locating user's position is as follows:

$$\tan(\theta_1) = \frac{x-x_1}{y-y_1} \quad (4.4)$$

$$\tan(\theta_2) = \frac{x-x_2}{y-y_2} \quad (4.5)$$

This requires measurement from atleast two different base points and it is prone to multipath effect.

4.4.4 Received Signal Strength (RSS)

All of the techniques discussed above have some drawbacks. The lack of line of sight during the propagation of signals is and multipath and fading effect due to physical obstacles degrade the performance in these techniques. The simplicity and low in complexity feature of RSS makes it a leading candidate of among all of these. It is based on the following formulas:

$$PL = PL_{1metre} + 10 \log(d^n) + s \quad (4.6)$$

PL is the path loss , PL_1 is the 1 meter reference of path loss , d is the distance between receiver and transmitter, n is path loss component and s in shadow fading.

4.4.5 Comparison of Four Measurement Models

Means of Measurement	Time Synchronization	Relation with LOS	Accuracy	No. of Receivers Required
TOA	all receivers and Mobile device	Required	High	≥ 3
AOA	No requirement	Required	Medium	Antenna
TDOA	All receivers	Required	High	≥ 2
RSS	No requirement	Not required	Medium	≥ 3

4.6 Fingerprinting Algorithms

It is based on the mobile device and the nature of radio signals in that area. It is the process of mapping a user's location with the help of their personal devices on which Wi-Fi is enabled. The RSS (Received Signal Strength) from various WAP (Wi-Fi access points) are measured and from this data the latitude and longitudes of the user's location are estimated. This method works for both indoor and outdoor locations where Wi-Fi is enabled. Fingerprinting can be majorly divided into two parts first is the calibration phase and then the positioning phase. In calibration phase the location of the reference points are stored in a database beforehand. The user's location data of a certain area is gathered beforehand for training purposes and then the testing is done based on information gained while training.

But, due to the wavering nature of the scenario we are working in the parameters on which we are dependent on to predict the outcome may change, like change in the number of access points ,change in the number of smart phones or their types, change in the number of users in the area. Such variability in the environment affects the results negatively and increases the error quotient in the result. So, to enhance the outcome appropriate assortment of algorithms and parameters have to be done to attain maximum output. In terms of fingerprinting algorithm it is mainly divided into two parts.

- **Deterministic Algorithm:** It attempts to find the minimum statistical signal distance between the detected RSSI location vector and the location vectors of various calibration reference points.
- **Probabilistic Algorithm :** It uses probability inferences to determine the likelihood of a particular location given that a particular location vector array has already been detected.

4.6.1 Nearest Neighbor Algorithm (NN)

It is one of the least complex and earliest algorithms , it uses Euclidean distan to calculate the distance between the RSS at an unknown location and the mean values of access points stored in the database beforehand and then choose the minimum value from it. Assume $S_m = \{S_{m1}, S_{m2}, \dots, S_{mn}\}$ is the array of real-time signal strength mean values measured at an unknown location and n is the number of APs, $S_{m1}, S_{m2}, \dots, S_{mn}$ are the

signal strength mean values from , and respectively. is the array of signal strength mean values of all the RPs in the database, where AP_1 and S_{i1} is the signal strength mean value from and is the signal AP_1 AP_2 strength mean value from respectively, The Euclidean distance can be then defined as:

$$d = \sqrt{(S_{m1} - S_{i1})^2 + (S_{m1} - S_{i1})^2 + \dots + (S_{m1} - S_{i1})^2} \quad (4.7)$$

4.6.2 k-Nearest Neighbor Algorithm (k-NN)

It is an extension of the nearest neighbor algorithm, where k stands for minimum Euclidean distance. With the given Euclidean distance between the mobile device and the access point , it is first identified when k is greater than or equal to 2. If $k=1$, KNN turns to NN. Assume the Euclidian distance and the signal strength vector of the mobile user is, $\{RSS_{i1}, RSS_{i2}, \dots, RSS_{in}\}$ where RSS_{in} refers to the RSS of AP_{in} at RP_i , then the Euclidean distance can be calculated by the following formula:

$$d_i = \sqrt{\sum_{k=1}^n (RSS_{ik} - RSS_k)^2} \quad (4.8)$$

4.6.3 Weighted k- Nearest Neighbor Algorithm

Same workflow as k-NN it generates final result through weighted mean k positons. Assume is the array of real-time signal strength mean values at unknown locations and n is the number of Aps; $\{S_i, S_j, \dots, S_n\}$ have the minimum Euclidean distances to , is the location corresponding to , $j=1 \dots k$. The estimated location (EL) can be calculated by :

$$EL = \sum_{j=1}^k \frac{1}{d(S_j, S_m)} \times \frac{L_j}{\sum_{j=1}^k \frac{1}{d(S_j, S_m)}} \quad (4.9)$$

Chapter 5

Framework

The framework proposed in this thesis is discussed in details in the following chapter. It is divided into three phases which have their own important functionalities. The fundamental behavior of each framework and their outcome is shown in figure 5.1.

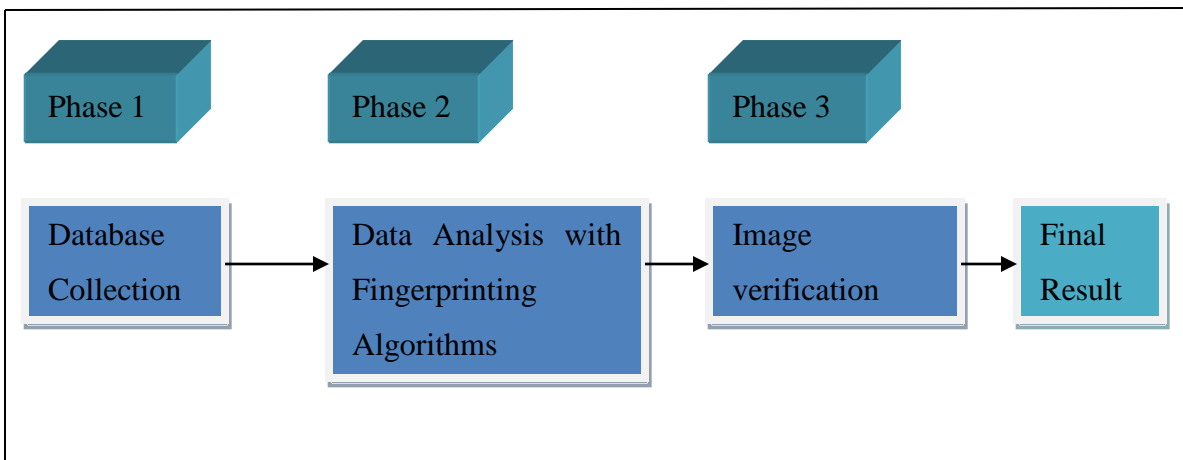


Figure 5.1 Proposed Framework of indoor user localization

5.1 Phase 1

In this phase the collection of database is done , There are various hardware and software requirements for this phase to be completed. Following are the hardware used in the completion of this phase:

- Rukus r500 , indoor Wi-Fi access point with a range of 2.4-2.5 GHz, 802.11ac .
- 2 different android enabled smart phones.

to save the received signal Strength from Wi-Fi an off the shelf commercially available application is used. Which gives the product in the form of a text document as shown in figure 5.2.

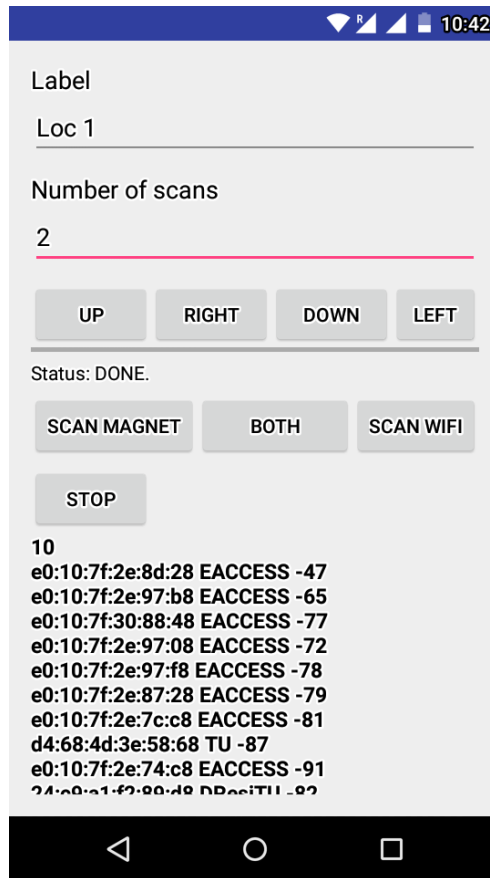


Figure 5.2 screenshot of Wi-Fi Fingerprinting application

This application is run on the Smart phones used at different points of experimentation. This work is carried out in the Building of Thapar University, and the emphasis is mainly laid on 2 particular blocks. The field of experimentation contains 13 corridors and 6 junction points. 5 of these corridors over constrained with walls on three side and the rest have walls on 2 sides. The one with 3 sides has no GPS signal received when it is checked upon, thus creating a perfect scenarios for indoor positioning. The data received at each point of experimentation is then clubbed together. The accumulated data is then cleaned and transformed for further proceedings. The number of access points from which data is recived together comes out to be 108. Different points of experimentation are fixed and are shown in figure 5.3.

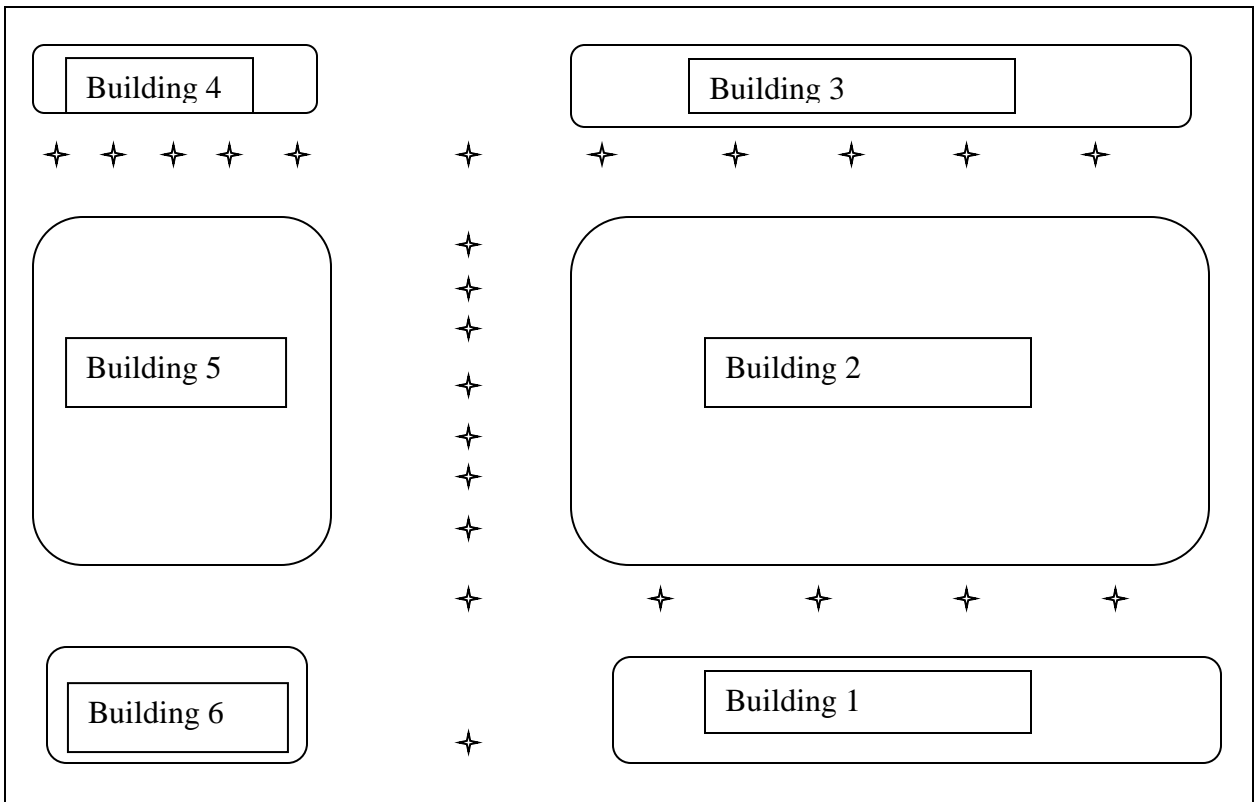


Figure 5.3 Points of experimentation on a floor

5.2 Phase 2

In this the cleaned data received from the previous phase is worked upon. The database now created will be analysed with the help of three fingerprinting algorithms namely Nearest Neighbor , k- Nearest Neighbor and weighted k- Nearest Neighbor. The results from these algorithms and analysed and the best result is picked.

5.3 Phase 3

To remove any ambiguity in the result of the previous phase due to fading and multipath effect this phase is added in the framework. Images of the point of experimentation are put together and an image database is created. Each image is then run through an off the shelf open source image recognition software. Which as a result gives us labels to identify as to what is present in the image. From these labels particular labels like ,girl, boy, woman, man, human are searched by and if present the positing of the user at that

point of experimentation is given affirmation. Thus the verification processing of confirming a user's presence in a particular is completed.

Chapter 6

Results and Analysis

There are multiple results obtained in the course of this work, that is one for each phase. Phase 1 gives the output of cleaned and organized data. Phase 2 of the framework gives us the accuracies obtained by each algorithm which can be seen in figure 6.1.

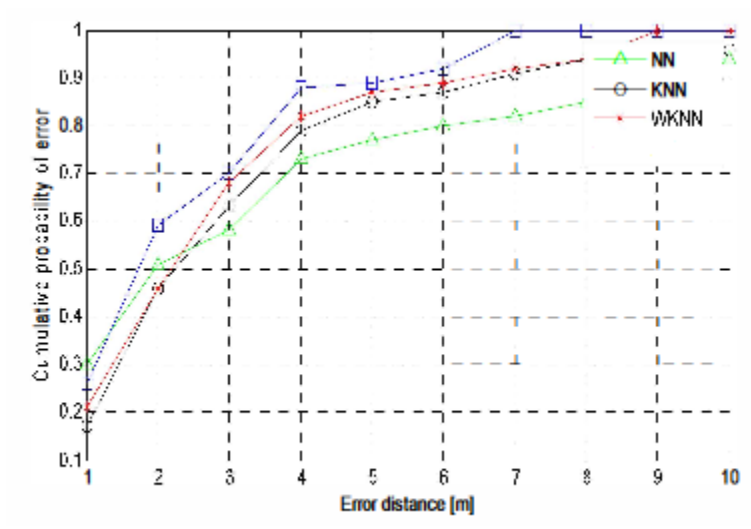


Figure 6.1 Error distance in each algorithm

After obtaining this result that can be seen in table 6.1.

Table 6.1 Localizatoin Errors of Fingerprinting Algorithms

Sno.	Algorithms	Localization Error
1	NN	5.6123 m
2	K-NN	4.0211m
3	W K-NN	2.8111m

the results of the best algorithm is chosen . This result is then verified with results obtained from the image identification in the form of an excel sheet and the final result that is generated is then analyzed to obtain the final result. The positioning error of the final result in this research comes out to be 2.54 meters.

Chapter 7

Conclusion and Future Scope

7.1 Conclusion

A huge market potential and swift development of smartphone features and technology are briefly discussed in this work. It can be seen that the marriage of smart phones and Wi-Fi fingerprinting to obtain the user localization is a mainstream direction in research. The obstacles that researchers have faced in obtaining results of user's localization have been discussed with the establishment of the idea that Wi-Fi fingerprinting through RSS in correct path with smartphone being the best companion to obtain the goal of user localization.

In this thesis the usage of state of the art localization techniques using Wi-Fi fingerprinting and image evaluation has led to the design of a localization framework which in turn has given us enhanced results. In initial phase of the framework we have collected the data with the help of open source off the shelf application. The collected data in turn has gone through various data cleaning, integration and transformation techniques thus, making it suitable for analysis and performance evaluation. This final data obtained is managed and processed through various fingerprinting algorithms and the results are assessed to analyze the performance based upon accuracy obtained.

The effects of multipath fading in Wi-Fi fingerprinting due to signal attenuation have been minimized with the help of visual database thus, enhancing the accuracy of the proposed framework. The achievable prediction accuracy of a user's location is seen to be around 2.4 meters of range. The results obtained have established evidence that with the help of enhanced Wi-Fi connectivity and improved image evaluation techniques,

indoor localization using the proposed framework are achieved with high accuracy without any additional hardware requirement. With the improvement in Wi-Fi network adaptors in smart phones this way of obtaining a user's location can be improved in the near future.

7.2 Future Work

This section gives a brief identification of future research directions that can be worked upon in coming time:

- A platform can be developed that collects real time data on the client side, evaluate the results on server side and display results easily to the user.
- Reducing the time complexity of the evaluation of the result.
- The increasing use of hotspots in smart phones has a major setback on posing using Wi-Fi fingerprinting. As the network adaptors are incapable of differentiating between received signal from a Wi-Fi hardware or a mobile hotspot. The changing position of a mobile hotspot makes the data obtained ambiguous thus, increasing the false positives in the result obtained.

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